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by

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HARTMANN WAVEFRONT DETECTION UNDER EFFECT OF BEACON INTENSITY

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ABSTRACT

The effect of beacon intensity on wavefront detection by the Hartmann wavefront sensor is reported, both in experiment and in numerical simulation. In addition, the tilt variance due to the variation of beacon intensity is analyzed.

KEY WORDS: beacon intensity, wavefront detection.

I. Introduction

Adaptive optics systems have been well known as an important means of calibrating phase anomalies in atmospheric transmission for laser beams. One of the principal applications of these systems is to detect wavefront phase information of a beacon from appropriate targets. However, the detection precision of wavefront

information directly affects the conjugate restoration calibration of the wavefront. Tyson et al. [1] conducted some theoretical analyses on the error in Hartmann wavefront detection, deriving an equation for the error in wavefront detection

$$\sigma^2 = K/(\mathrm{SNR})^2 \tag{1}$$

In this equation, K is the system parameter; and SNR is the signal-to-noise ratio of detection. Eq. (1) signifies that the detection error will be very high when the signal-to-noise ratio is relatively small. This is a problem that is unavoidable in engineering applications of actual laser atmospheric transmission. In other words, the intensity of the beacon source is frequently weak when arriving at the detection end. However, what is rarely reported at present is how beacon intensity affects the wavefront detection precision, and the study of the closed-loop effect in the system, especially in descriptions from the experimental approach.

This article reports on an experimental study of wavefront detection errors affected by different beam intensities, using a Hartmann wavefront detector of the 37-element adaptive optics system developed at the Institute of Optics and Electronics, Chinese Academy of Sciences. The experiment provides data on the quantitative relationship between wavefront detection error and beacon intensity variation in the system. In addition, the effect on the closed-loop control of the adaptive optics system is shown when beacon intensity decreases.

II. Measurement Method and Results in Experiment

Fig. 1 shows the optical path in the experiment. The beacon is reflected by tilt lens TM and deformation lens DM prior to reaching the Hartmann wavefront detector. Through an A/D converter, a computer extracts tilt information in various light sub-spots of the beacon after dissection after passing through the A/D converter. The extracted tilt information is the raw data for conjugate restoration calibration of the main laser wavefront. The article makes the investigation by using variance of this tilt data as the error in Hartmann wavefront detection. In the experiment, the beacon intensity arriving at the wavefront sensor is changed by using a polarized lens P at the emitting terminal of the rotating beacon. Meanwhile, the relative signal intensity is monitored with a optoelectronic wattmeter.

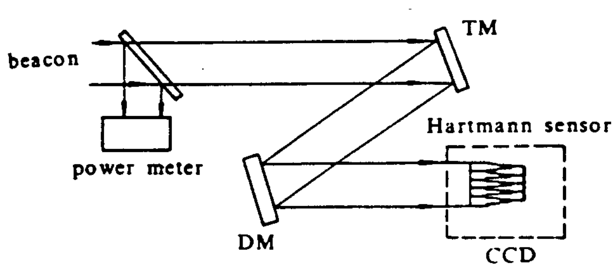

Fig. 1. Experimental layout

To reduce atmospheric perturbation and to focus on the effect of tilt detection due to variation in beacon intensity, the experiment was conducted under quasi-steady atmosphere conditions. Adjust the A/D converter in order to attain collecting conditions

with the maximum dynamic state at maximum beacon intensity so that the measured tilt variance is at a minimum. The actual physical implication of such measurements is the following: during weak atmospheric perturbation, what will be the effect on measurement tilt variance imposed by different beacon intensities? Fig. 2 explains this physical implication. In the figure, (a) is the light intensity distribution of a relatively intense beacon; (b) is the light intensity distribution of the weaker beacon. A - A' is the sampling zero point overcoming the noise. Their respective light intensity centers (in other words, the beacon wavefront tilts) are situated, respectively, at OO and O'O'. However, it is impossible to obtain absolutely stationary (a) and (b). Therefore, in the article tilt variance during the quasi-steady state (weak perturbation) conditions is used to analyze the detection error. At various beacon intensities, all detection tilt variances are statistically obtained from picture data collected in multiple frames.

Instrumental data: the A/D dynamic range of the Hartmann sensor is 8bits; the sampling rate is 380fps; the subaperture of the 37-channel collection is 16x14 pixels; the actual sampling rate in calculating the center of gravity for 37 light spot channels is approximately 40fps; all the measurement data are statistically derived from data in more than 1000 collected frames.

Fig. 3 shows the relationship between relative variation of

detected tilt variance and beacon intensity. "*" denotes the experimental points. In the figure, curve a and simulation result b as calculated from Eq. (1) are shown. The numerical simulation method is basically similar to the method in reference [2]. What is different in this case is the addition of Gaussian white noise on the imaging plane. The mean square error of noise amplitude is 4 in the 8-bit A/D conversion, corresponding to 1/50 of the maximum unsaturated light intensity in the A/D conversion. In other words, numerical simulation involves considering 1/50 (after standardizing the wavefront detected maximum light intensity of the stationary-state small perturbation) as the interruption signal (this corresponds to AA'=1/50 in Fig. 2). Then, the simulated beacon intensities decrease each time, arriving at the numerical simulation result of beacon intensity with respect to the wavefront detection effect. Deviations in experimental and calculated values stem from two factors. One is the quantization error of the system; the other is the divergence error of CCD pixels. Since these two factors are not considered in the calculations, when the beacon is weaker as seen from the figure, the effect due to beacon intensity is the main factor causing the detection tilt error. At that time, the experimental value agrees better with the calculated value. When the beacon is more intense, the detection error caused by the two above-mentioned factors appears as quite noticeable. Both errors partially increase the system detection error. On the other hand, when applying Eq. (1) to calculate the effect on detection error due to beacon intensity variation, the noise

portion in (SNR) is marked in the system parameter K. Therefore, Eq. (1) becomes:

$$\sigma^2 = K'/S^2 \tag{2}$$

In the equation, S is the ratio between signal light intensity and the maximum light intensity. In other words, noise and error intensity are separately considered in the calculations. However, in the actual detection process, as shown in Fig. 2, the sampling process involves separating the weak light signal (submerged in noise) together with noise. Thus, the signal light submerged in noise is interrupted. In other words, the signal light intensity submerged in noise (or, the ups and downs of signal light intensity with noise) has an effect. However, in the experiment the relationship between the detected tilt variance and beacon intensity is a secondary inverse proportion. From Fig. 3, we can see when the beacon decreases down to 1/10 of its maximum intensity (relative light intensity), the detected tilt variance is two orders of magnitude greater than the beacon tilt variance. This directly affects the adaptive optics system to use the detected wavefront tilt as the original basis to control the wavefront restoration calibration of the main laser beam by deformation lens and tilt lens. Actually, for the specific adaptive optics system under the quasi-steady atmosphere conditions in the experiment, when the beacon decreases to 0.15 of the maximum unsaturated detection light intensity, the steady closed-loop control at deformation lens disappears. In other words, there is no effect of dynamic calibration.

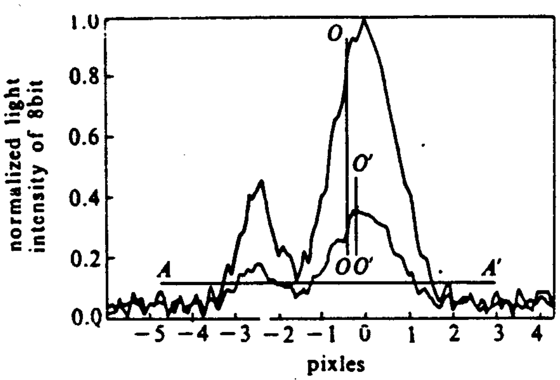

Fig.2 Sampling Demostration (Pixels)

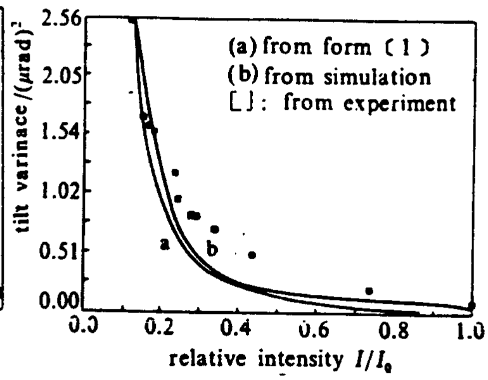

Fig.3 The variation of tilt variance with beacon relative intensity I/I_0, where I_0 is the maximum intensity not saturated

III. Conclusions

It is generally considered that wavefront detection errors are smaller quantities in various sector errors that can be neglected when calibrating wavefront anomalies of a light beam in an adaptive optics system. However, this is only a relative concept. In other words, when the beacon intensity is relatively high within the linear dynamic range of detector, the detection error is smaller by one to two orders of magnitude than the other errors in the adaptive optics system. When the beacon is weaker (a situation that may appear in actual applications), this error is quite noticeable. As described in the article, when the beacon in the specific system decreases to 0.1 of the maximum unsaturated detection light intensity, the detection error will be increased by two orders of magnitude, thus approaching the other errors. Since wavefront detection is the first sector of the adaptive optics system, the error increase will prevent the closed-loop state from

appearing in the entire system.

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